



**Technology
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*Surveying the World's
Longest Tunnel*

Bay Bridge Slide

Scanning on the High Seas

Peru's Camiara Road Project



Surveying the Longest Tunnel in the World

Profile check in the tunnel access section using a Trimble S8 Total Station.

Occupying the primary north-south transit corridor in Switzerland, the New Rail Link through the Alps (NRLA) is a key component in Europe's growing network of high-speed railways. When completed in 2017, the NRLA and its high-speed AlpTransit trains will cut the travel time between Zurich and Milan by more than 25 percent. The centerpiece of the new system is the Gotthard Base Tunnel. At 57 km (35 mi) long, it's the longest tunnel in the world.

The Swiss surveying company *terra vermessungen ag* is providing a variety of surveying services in the northern sections of the Gotthard tunnel. The diverse work, demanding requirements for precision, and difficult working environment present unique challenges for the surveyors and their equipment.

One of the biggest hurdles comes from the narrow sight lines in the tunnels. When sighting in a tunnel, it is common to have multiple prisms visible in a total station's field of view. Manual observers can distinguish the desired target from the others but this approach is too slow for the project's needs. To solve the problem, *terra vermessungen* selected the Trimble S8 Total Station. The 1" robotic instrument combines precise measurement with Trimble FineLock™ target technology to provide automatic pointing and fast, high-accuracy measurements in the confined spaces.

High-Precision Control

Two giant tunnel-boring machines (TBMs) are at work on the project, each capable of excavating up to 40 m (130 ft) per day. To keep the machines moving, the surveyors maintain and expand the tunnel's network of control points.

The surveyors extend the networks by about 200 m (660 ft) at a time. For each new control point, crews install threaded bolts into the tunnel walls or floor. Extending the control network usually requires three instrument setups over two hours, in which the Trimble S8 makes multiple measurements to approximately 25 targets.

The measurements are collected using Trimble Survey Controller™ Software running on a Trimble TSC2 Controller, then downloaded and analyzed in the jobsite office. To verify the internal accuracy of the measurements, surveyors compute an adjustment using an unconstrained network, and then use a Helmert transformation to move the unconstrained network onto the existing tunnel control. Maximum residual errors must not exceed one millimeter. The new points will serve as control points until the TBM moves ahead. Then they are replaced with new points during the next network extension cycle.

Deformation Monitoring

Tunnel construction sometimes causes alterations by changing loads in the surrounding rock. The resulting deformations occupy relatively small areas called convergence zones, and typically occur in known fault zones or areas with visible cracks or falling rock. Surveyors monitor these areas by collecting periodic cross-section measurements.

Initially, the behavior of the deformation is not known, so the surveyors need a flexible and expandable approach to monitoring the convergence. They can start with conventional measurements using the Trimble S8 and TSC2. If necessary, the team can convert to an automated monitoring system, remotely controlling the Trimble S8 to take continuous observations without the need for a surveyor at the instrument. Once the rate of deformation subsides, the crews can resume conventional methods of monitoring.

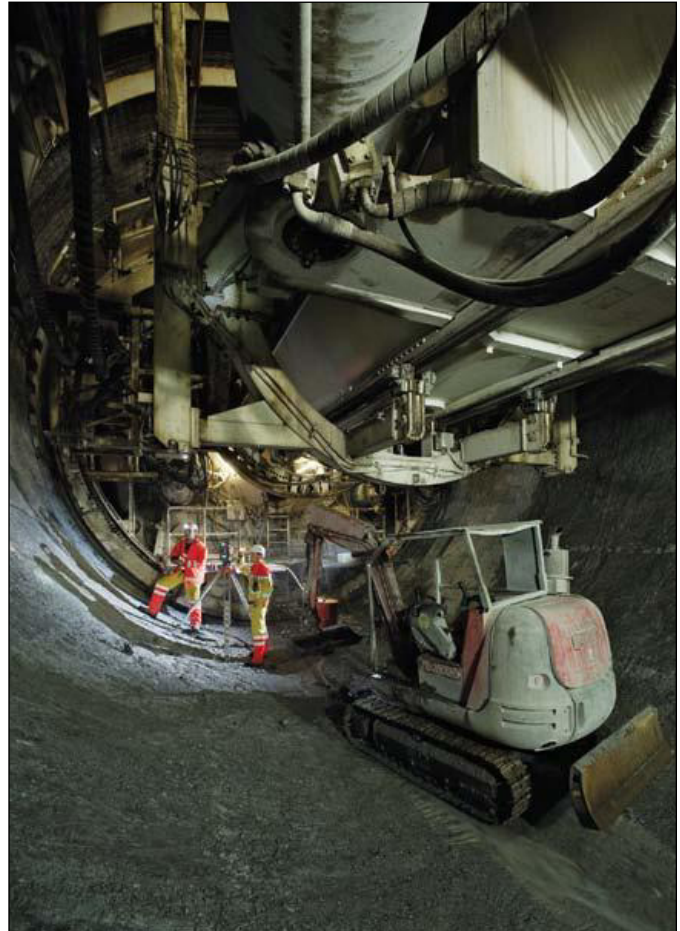
Solving an Explosive Problem

Tunnel sections that are short or have irregular cross-sections are often constructed using the blast and muck method. In this approach, a jackhammer bores holes several meters into the heading face. The holes are filled with explosives and are fired simultaneously.

Immediately after the blast, the tunnel face is littered with rock material and access to the face is prohibited until the rock is stabilized. However, the tunnel crew is in a hurry to remove the rock material, and the heading foreman wants to know immediately if further blasting will be needed to achieve the required profile. Each blast creates a new cavern 2 to 5 m (6 to 16 ft) deep and accurate surveying is needed before any decisions can be made.

For this work, *terra vermessungen* uses a Trimble VX™ Spatial Station and a “motorized laser” approach. The Trimble VX is attached to the tunnel wall approximately 100 m (330 ft) behind the heading face. The crew uses the free stationing routine in Trimble Survey Controller to determine the instrument’s three-dimensional position in the tunnel coordinate system. Information on the tunnel’s design alignment and profile are stored in the Trimble TSC2.

Soon after a blast, the heading foreman uses the robotic function and red laser of the Trimble VX to measure numerous locations on the face. The measured points are compared to the design stored in the Trimble TSC2, and any deviation from the required profile is displayed on the control unit. Urs Müller, survey engineer for *terra vermessen*, said that the video capability of the Trimble VX is



Measuring profiles directly behind the TBM's head enables TBM guidance to be checked independently.



Concrete transport train in the tunnel.



Mounting bi-reflex targets for convergence monitoring.

especially useful. “In the poor lighting conditions, they really appreciate the video display,” he said. “It helps the foreman know he is pointing to the correct spot.”

Every few days, surveyors check the measurement configuration and the quality of the free-stationing solutions. When the tunnel advances by 50 m (164 ft), the instrument is moved ahead to a new position. For the tunnel-driving crew, the main benefit of this approach is that the heading foreman can quickly measure the results of each blast.

According to Müller, the Trimble technology has lowered the cost of surveying on the blast tunnels. It lets them use their surveying team more efficiently at each heading face and has eliminated delays in waiting for qualified staff to arrive.

Scanning with Trimble VX

During the excavation process, tunnel walls are sprayed with shotcrete. After the first application of shotcrete, the surface of the tunnel is measured for quality assurance. To do this, the Trimble VX Spatial Station is set to automatically measure profiles at intervals of 1 m (3.3 ft) over portions of tunnel 60 m (197 ft) long, collecting points every 50 cm (20 in) on each section. The resulting profiles are stored in the TSC2, and the process to capture and store 61 profiles takes less than one hour. The construction teams use the data to optimize the inner concrete formwork. Müller said that optimizing the concrete thickness to 3 cm (1 in) leads to savings of one cubic meter (1.3 yd³) of concrete for every one meter (3.3 ft) of tunnel.



Scanning the shotcrete surface using a Trimble VX Spatial Station.



Northern portal structure of the 57-km-long railway tunnel near Erstfeld, Switzerland.

Setting-Out Underground

One of the most demanding setting-out projects is the alignment of the TBMs. Each TBM is more than 400 m (1,300 ft) long, and the concrete blocks that support it must be placed accurately. Working beneath the machine, surveyors install profile points on the tunnel walls at intervals of 10 m (33 ft). Each TBM advances approximately 30 m (98 ft) per day, and crews need to set out six points at a time.

To locate the profile points along the fluctuating tunnel walls, the crews use the Trimble S8 and Trimble Survey Controller routines for tunnel setting-out. The Trimble S8 automatically turns to the correct direction and makes iterative measurements until the appropriate point is found on the tunnel wall. It then shines a red laser dot on the point. The surveyor marks the spot with a rock anchor and records the point for analysis and quality assurance. Typically, it takes less than one hour to set up the instrument and set six points into the tunnel walls.

As Gotthard construction progresses, *terra vermessungen* will continue to keep their Trimble systems busy. For the TBMs alone, *terra vermessungen* will set out approximately 7,000 points. Müller is pleased that the new technology has repeatedly proven its value. “After a few hours, the skeptical attitude of the heading foremen changes,” he explained. “And after a few days, they do not want to continue without it.”



Checking the inner concrete formwork using a Trimble S8 Total Station.